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THE DEVIATION OF PROFILES OF EMISSION LINES OF PROMINENCES FROM A DOPPLER PROFILE

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ABSTRACT

The profiles of the emission lines in four prominences were measured. Special attention was paid to the photometric procedure, the accuracy of intensity measurements is 1-2%. The astigmatism of the spectrograph and the asymmetry of the instrumental profile were determined. The graphical method ($\Delta\lambda^2$, lg I) was used for obtaining more precise data about the profiles. Some of the observed profiles have the form of a Gaussian curve in the core of the line, but deviate appreciably from it in the wings. Some other profiles deviate from the Gaussian curve in the center of the line, because of self-absorption. For most of the profiles the halfwidths were determined with an accuracy of 1-3%.

The following conclusions were made from the derived results: 1) the cores of the profiles of weak hydrogen and metallic lines and also He λ 3889 are broadened mainly by the Doppler effect; 2) formula (3) for the self-absorption of radiation in a homogeneous layer cannot be applied to prominences; 3) the cores of the profiles of Hα and Hβ are not Doppler profiles with self-absorption; 4) the helium line D_3 and λ4471 are broadened by the Doppler effect and other processes; 5) the value $\frac{\Delta\lambda}{\lambda}$ increases but slightly with the number of the Balmer line for the high members of the series; 6) the strongly developed extreme wings of the profiles of the bright lines of H and K Ca + and helium cannot be explained by the presence of a hypothetical very hot gas in a comparatively cold envelope; 7) besides the Doppler shift of the Hα and D_3 lines, non-Doppler shifts are also observed.

1. ON THE METHOD OF PROCESSING THE MATERIAL

The processing of spectrograms of prominences obtained on the spectroheliosope [1] indicates the existence of some deviations of the line profiles of prominences from the Doppler type. These deviations, however, are so small that they are not revealed with certainty because of the inadequate resolving power and moderate dispersion of the spectrograph on the spectrohelioscope.

The Baschen Solar Telescope of the Crimean Astrophysical Observatory [2] allows examination of the line profiles of prominences in greater detail. On the BST diffraction spectrograph Hα, Hβ and D_3 were photographed in the second order of the spectrum with a dispersion of ≈0.75 A/mm, and the lines in the violet part of the spectrum were photographed in the third order with a dispersion of ≈0.5 A/mm. The dispersion was 5 times greater for the first three lines, and 15 times greater for the violet than the dispersion of the spectrograph of the helioscope The new spectrograph has considerably greater resolving power. the actual resolving power was increased by 16,000, to 165,000 and 250.000, respectively, for the red and violet parts of the spectrum.

In order to obtain the most accurate profiles possible for revealing fine details, it was necessary to improve the method of processing the spectrograms and to increase the precision of measurements. In particular, we abandoned the use of the earlier method of smoothing out the drawings by means of superimposed penciled drawings, which introduced elements of individual error of the photometrist into the processing The following measures were also adopted.

The measurement of the spectrograms was carried out on the MF-2 microphotometer. As in [1], after the measurement of a spectrum of a prominence, the scattered light superimposed on the spectrum, - i.e., the halo- was measured for the same readings of wave length. The subtraction of the spectrum of the halo was carried out numerically for each wave length, after conversion of the measured density into intensity. Measurement on the MF-2 has advantages over measurement on the Moll microphotometer or MF-4, since, firstly, the value of the measured density can be obtained with greater precision than on a drawing (errors equal to 0.1% for a reading of 1000 on a non-exposed section of the plate), and secondly, the laying-out of smoothed profiles on the record can introduce inaccuracies due to the presence of slight blends near a line, indistinguishable from grain fluctuations. Even where large "blends" occur, the "smoothed" profiles are sometimes

arbitrarily constructed over absorption lines not associated with that measured. Although in algebraic subtraction of intensity of one spectrum from another the results contain double the average error because of the grain of the photo-emulsion, this error has only a random character, allowing the use of the methods of the probability theory. In our opinion, the method of algebraic subtraction has advantages for determination of the wings of profiles.

A large-scale image of knots of prominences on spectrograms permitted the use of a slit of 1 X 0.02 mm on the spectrogram, which was appreciably greater than the size of the grain. As a result, fluctuactions of density due to granularity of the photo-emulsion on the background or on uniformly exposed portions of the plate were less than 1%.

In the process of measuring, we controlled not only the null reading but also the sensitivity of the photo-element. For this purpose, after every 10 measurements the reading of the photo-element was checked at some fixed point on the plate, for example, on an absorption line chosen as a check-point. Thanks to this, the repetition of readings was within the limits of a fraction of a percent.

In order to obtain characteristic curves of plates for given wave lengths the following method was used. The solar spectrum was photographed through a nine-stepped wedge, placed in front of the spectrograph slit. Measurements were made at several points of the continuous spectrum taken with some over-exposures and also within several lines. After this, points were marked on the drawing ($\lg I$, A/Φ), and, by means of displacement of the points of each series of measurements along axis $\lg I$, all of them were arranged in one curve, defined, now, by no less than fifty points (A is the reading of density according to the uniform scale of the microphotometer, Φ is the reading on a non-exposed portion of the plate). A curve is drawn through the points, from which the value of $\lg I$ is taken at equal intervals A/Φ. Subsequently the table of value I is smoothed by means of the equalization of the path of the second difference. The table obtained by this means represents a smooth function which is especially important for establishing photometric differences of two close values of intensity, as, for example, in the wings of a line. Interpolation in the table is employed for intermediate values of I.

We now consider the causes of some photometric errors. Usually the larger errors are connected with granularity of the photo-emulsion, inaccurately determined characteristic curves, and shortcomings in construction of smoothed profiles. It is evident from the above that

these errors can be sharply reduced. There remain errors connected with some nonuniformities of the photo-emulsion, irregularities in sensitivity, and possibly, even changes in characteristic curves of plates. Similar phenomena are observed very markedly on old photographic plates. Hence the determination of absolute values of intensity often contains errors of 5 and even 10%, especially when based on measurements of portions of a plate that are far distant from each other.

In our case, we carried out measurements of line profiles that covered small intervals on the plate, - on the order of 1 - 3 mm. Moreover, in the case of prominences the resulting profile is the difference between two profiles measured on adjacent portions of the plate differing little from one another in density, especially in the wings of the profile, i.e., differential effects are being measured. Hence, the average error of one measurement is 1 - 3% and lower. We must emphasize that this error pertains to the measurement of total intensity of the prominence and scattered light. For those lines of the prominence, the intensity of which is less than the intensity of the scattered light, the relative error of the measurements of the same profiles $\Delta I/I_m$ actually will be greater. In addition, since profiles are obtained by subtraction of one spectrum from another, the average error is doubled. Nevertheless, I succeeded in determining the wings of some profiles to 0.01 of the intensity of the maximum or less, and also succeeded in measuring profiles of such faint lines in the emission spectrum of a prominence as H_ζ, H_9, He λ 4471, Ti^+ λ 3685 and others. As an example, in Fig. 1 are presented results of measurements of profiles of one of the portions of the prominence photographed on July 13, 1955.

In some cases, for measured profiles photographed on old Ilford-Zenith plates, one wing is found to be raised and the other depressed by 1 - 2%, as is apparent in Fig. 1. Apparently this is connected with the change in sensitivity of the emulsion along the direction of dispersion, and we will not make substantial errors if we calculate this change using a linear approximation, since it is difficult to imagine sharp jumps in sensitivity along the plate.

In my own work in the determination of lines of the 5th series of He II in the spectrum of a star of the Wilson type Oe5 [3, 4], I obtained an accuracy of 0.3% in processing photographs of the spectrum, and I measured lines with intensities of less than 1% of the intensity of the continuous spectrum. Such accuracy was achieved by means of a combination of un-smoothed measurements of several negatives, carried out on a non-recording microphotometer. As a result of the averaging of many unsmoothed measurements, random fluctuations caused by the

grain of the emulsion were diminished, and faint absorption lines became apparent which fade out and are masked by errors due to granularity of the emulsion on individual spectrograms. A similar phenomenon took place in measurements of spectra of prominences. The long slit of the microphotometer, thanks to its large area by comparison with the size of the grain of the emulsion, averaged random fluctuations in density caused by granularity, and registered true changes in brightness in the spectra. The difference from Wilson's treatment is that he averaged intensities and we averaged densities.

In a spectrogram the spectrum of a prominence is superimposed on the spectrum of scattered light from the atmosphere and from the instrument. The major component of scattered light is usually connected with the instrument. In the BST the scattered light, apparently, is mainly caused by the dust on the mirror, its intensity being about 1% of the intensity of the solar disk. If a telluric line falls on the emission spectrum of a prominence, then, after subtraction of the halo spectrum, the impression of absorption lines of the earth's atmosphere remains on the line profile of the prominence. This phenomenon was observed, for example, in photometry of line Hα in a prominence, photographed at a low elevation in the evening of July 24, 1955. The line of the earth's atmosphere λ6563.53 was found superimposed on a very broad emission line of this prominence. On the spectrogram it is clearly visible that the impression of a narrow line, characteristic of the atmosphere, was left. This conclusion was confirmed also by the accurate determination of the wave length of the absorption line. No evidence of the line Co λ6563.42 (see [5]) was observed simultaneously. However, such broad lines are rarely observed in prominences. Among other emission lines of prominences subject to the influence of telluric lines, one should mention D_3. This influence is usually slight, since all four atmospheric absorption lines that fall on D_3 are weak.

In the determination of wave lengths of emission lines of prominences by measurement of a spectrogram, the positions of the middle of several separate well-pronounced absorption lines in the sky spectrum were marked off to the left and to the right of the measured line. Since the halo is made up of scattered light from all of the solar disk, the absorption lines in its spectrum are broadened as compared with corresponding absorption lines in the spectrum of the center of the solar disk, but the wave lengths of these lines coincide with an accuracy of ± 0.01 A. Then, by means of the method of least squares, the equation of dispersion for the measured portion of the spectrum was found. Such a method provides determination of the equation of dispersion with an accuracy up to several thousandths of an Angstrom and permits the determination of the wave lengths of prominences with an accuracy to 0.01 A.

2. ANALYSIS OF THE INSTRUMENT*

Partial analysis of the BST spectrograph was carried out with a grating blazed for the second order of the spectrum. As in the helioscope [1] astigmatism was discovered, which was dependent upon the angle of the grating. The results of the measurements are given in Table 1.

TABLE 1

i	0°	10°	15°	20°	25°
f_M	96	98	100	102.5	104.5
f_c	96	98	95.5	93.5	91.5
Δf	0	0	4.5	9.0	13

In this table i is the angle between the normal of the grating and the direction of the entering light, f_M is the position of the mirror cell for meridional focus, f_c for sagittal focus and Δf is the astigmatic difference in millimeters. Within the limits of accuracy of the measurements f_M and f_c are symmetrically arranged relative to the central position of the mirror cell. Calculation according to formula (3), cited in [1]:

$$\frac{R}{R_{min}} = \frac{2L^2\lambda_0}{(2b_0)^2\Delta f} = \frac{2\cdot 10^8\cdot 5\cdot 10^{-5}}{2.25\cdot 10^4\cdot 1} = 0.4,$$

shows that the surface of the grating is only insignificantly inferior in quality to a first-class mirror.

We also determined the instrumental profile of the spectrograph for a working width of the slit equal to twice normal size. A krypton tube served as a light source. The green triplet λ5570 was investigated. The central portion of the profile in the first order of the spectrum satisfactorily represented a Gaussian curve with a half-width $\Delta\lambda_{instr} = 0.0445$ A. We must take into consideration that the half-width of the instrumental profile is so small that in its determination the width of the lines of the light source used will affect the results. Thus, for a spectrograph with great resolving power there occurs the difficulty of determining $\Delta\lambda_{instr}$, since it is impossible to measure extremely narrow lines if any light source is used. It is possible, however, to propose the following method of avoiding this difficulty. Since the instrumental and observed profiles, as well as profiles of source lines, have the form of a Gaussian curve, then

* Analysis of the instrument was carried out jointly with T. V. Kazachevskaya.

$$\left(\frac{\Delta\lambda}{\lambda}\right)^2_{obs} = \left(\frac{\Delta\lambda}{\lambda}\right)^2_{source} + \left(\frac{\Delta\lambda}{\lambda}\right)^2_{instr} .$$

On the other hand, as the measurements show (in agreement with theory), the half-width of the instrumental profile $\Delta\lambda^{(n)}_{instr}$ in the spectrum of the n^{th} order is proportional to n^{-1}, so that

$$\left(\frac{\Delta\lambda^{(n)}}{\lambda}\right)_{instr} \cdot n = A = \text{const.}$$

Thus

$$\left(\frac{\Delta\lambda}{\lambda}\right)^2_{obs} = \left(\frac{\Delta\lambda}{\lambda}\right)^2_{source} + \frac{A^2}{n^2} ,$$

i.e., $\left(\frac{\Delta\lambda}{\lambda}\right)^2_{obs}$ is a linear function of $\frac{1}{n^2}$. By measuring the line profiles in various orders of the spectrum we can, with the aid of this formula, determine both $\Delta\lambda_{instr}$ and $\Delta\lambda_{source}$. For example, the measurement of the iron-arc spectrum gave results agreeing with the results of measurements of $\Delta\lambda_{instr}$ using a krypton tube.

Since the half-width of prominence lines is > 0.15 A, and the spectra of these were photographed in the 2nd and 3rd orders, the instrumental profile does not influence the determination of half-widths of lines.

As in the helioscope [1], the instrumental profile has some asymmetry which is especially strongly revealed in the wings. At a great distance from the center of the instrumental profile, in the 1st order of the spectrum, the red wing is roughly twice as intense as the blue. Staring with a value of intensity of 1 - 2% of maximum intensity, $I \sim \Delta\lambda^{-a}$ in the wings of the profile, where $\Delta\lambda$ is the distance from the center of the profile measured at its peak. For the red wing $a = 3.56$ and for the blue $a = 3.88$.

3. DESCRIPTION OF THE OBSERVED MATERIAL

The photography of spectra was carried out chiefly in the morning to obtain good images, permitting us to see the photospheric granulation distinctly. The ultraviolet portion of the spectrum was photographed on old Ilford-Zenith plates, and Hα and D_3 were photographed on Agfa red-rapid plates. Exposures for each line of the prominence were held within the limits of from 10 sec. to 1 min.

Profiles of lines in the spectrum of the prominence photographed on July 13, 1955 were investigated in greatest detail. The rest of the prominences, descriptions of which are given below, were investigated in less detail.

On March 23, 1955 spectra of four low small prominences were photographed, simultaneously falling on the slit of the spectrograph, and tangential to the image of the sun. This was done on 2 sections. On the section situated near the sun, regions were photographed that were transitional between the prominences and the chromosphere, but precise fixation of their positions simultaneously for all photographed lines of the spectrum was very difficult.

The prominence of May 13, 1955 consisted of 2 parts. Part 2 was further from the sun and had the form of a suspended cloud. Simultaneously, at the base of the prominence a faintly luminous knot was observed moving with great velocity.

One can distinguish 3 parts on the spectrum of the prominence of July 13, 1955. Part 1 is situated near the sun and has greater line width. Parts 2 and 3 are similar but have smaller Doppler shift than part 1. The spectra of the prominence are very bright and are rich in metallic lines.

On July 22, 1955 a developing coronal prominence was photographed. The process of photography of the spectral lines in the sequence H_α, D_3, H_β, $K\gamma$, H, K and H_δ occupied more than an hour. At the end of the survey the prominence disappeared.

4. RESULTS OF MEASUREMENTS OF PROFILES

The profiles of emission lines of prominences are, on the whole, Doppler, although some deviations are observed. We designate as Doppler those profiles which, firstly, have the form of a gaussian curve

$$I = I_0 e^{-\left(\frac{\Delta \lambda}{\Delta \lambda_D}\right)^2}, \tag{1}$$

and, secondly, the halfwidths of which satisfy the following formula:

$$\frac{\Delta \lambda}{\lambda} = \frac{1.665 \Delta \lambda_D}{\lambda} = \frac{1.665}{c} \sqrt{\frac{2RT_{kin}}{\mu} + v_t^2}, \tag{2}$$

where $\Delta \lambda_D$ is the Doppler halfwidth, T_{kin} is the kinetic temperature of atoms, v_t is the turbulent velocity, μ is the molecular weight, and c and R are known constants.

Some observed profiles have the form of a gaussian curve in the core of the line, but deviate from it in the wings. Other profiles deviate

from a Gaussian curve in the core of the line. The present work is devoted to the establishment of the character of these deviations. The elucidation of the question of the gaussian or non-gaussian character of the profiles has been carried out by graphical methods. For each measured profile a diagram ($\Delta\lambda^2$, lg I) was constructed, along one axis of which was laid out the logarithmic value of the measured intensities, and along the other axis - the square of the distance from the center of the profile $\Delta\lambda^2$. Obviously, symmetrical profiles with a gaussian form are represented on diagrams ($\Delta\lambda^2$, lg I) by straight lines. Hence, the use of such diagrams proves to be convenient for portraying asymmetry and deviations from a Gaussian form in the profiles. In the majority of cases investigated by us, line profiles of prominences proved to be symmetrical up to several percent of intensity I_{max}. In some cases, for prominences with appreciable velocities, asymmetry was discovered. Sometimes central portions of strong lines also proved to be asymmetrical.

The center of the profile was found in the following manner. As a first approximation, an arithmetic mean of the center of the profile was taken from the center of the span connecting the left and right wings of the profile on the drawing ($\Delta\lambda$, I), for several values of intensity. Then this value was more precisely defined with the aid of the ($\Delta\lambda^2$, lg I) curve. As an example, the typical curve pertaining to the measurements of $H\gamma$ on the prominence of July 13, 1955, given in Fig. 2, can be used in showing what degree of accuracy we can expect for determination of the center of the profile, and consequently for determination of wave lengths of spectral lines in prominences. The lower drawing is displaced relative to the upper one by a value lg I = 1.0 along the ordinate axis. On the diagrams, the coordinate $\Delta\lambda$ is measured not from the center of the profile, but from a point displaced 0.01 mm (0.005 A) from the center. For the upper drawing this displacement is toward the blue portion of the spectrum and for the lower it is toward the red portion.

On the upper drawing the points of the rectilinear part of the profile are situated, for the most part, approximately directly above, but on the lower drawing they are situated below. X's are arranged in reverse order. These drawings show clearly that $\Delta\lambda$ are not measured from the axis of symmetry. Such drawings served as sensitive criteria for the correctness of choice of center of the profile. The position of the center of the profile on the spectrogram was taken from the position of the center of the prominence line, which, - with the aid of the equation of dispersion, the determination of which is discussed above, - gave the wave length of the prominence line relative to the lines of the solar spectrum. As follows from the foregoing, the error in determination of these wave lengths is 0.01 A for bright lines, but is somewhat larger for weak lines, due to the increase in errors in determination of the

center of the profile. The results of measurements of wave lengths of prominence lines are given in Table 3 (Column 4).

In Fig. 3 are given examples of diagrams ($\Delta\lambda^2$, lg I), constructed for a series of lines of the prominence of July 13, 1955 (2). We will examine these drawings starting with the simple case of line H_δ. Here, the circles outline points taken from drawing ($\Delta\lambda$, I) after an average curve in the wings of the profile has been drawn on it. These points give an idea of the behaviour of the far wings of the profile. With the exception of the extreme portions of the profile, where intensity is less than 10%, the points of this graph are grouped around a straight line. In the wings, the points deviate from this straight line, indicating deviation of line profiles of prominences from a gaussian curve.

We turn now to the upper, gaussian portion of the profile. If we draw a straight line through the points on the drawing, from its inclination we can determine the halfwidth approximating a gaussian profile $\Delta\lambda_T$ with great accuracy. It is important to note that, firstly, the halfwidths, in such a determination, have all measured points in common, and, secondly observed values of intensity are used, i.e., the influence of personal error of the photometrist, introduced by the drawing of smoothed profiles, is eliminated. Computing the halfwidths analytically, we can also determine the average quadratic error of the results (see page 19).

All of the profiles of faint hydrogen and metallic lines of prominences investigated by us have gaussian cores. However, for lines H_α, H_β, and sometimes H_γ, deviation from a straight line, characteristic of self-absorption effects, is revealed in the central portions of the profiles on drawings ($\Delta\lambda^2$, lg I). The same thing can be said about lines H and K Ca^+.

Thus, profiles of prominence lines on drawings ($\Delta\lambda^2$, lg I) can be separated into 3 parts: 1) the central portion, where there can be said to be self-absorption, 2) the straight-line portion, stretching to 2 - 10% from I_{max}, and 3) the far wings, in which deviation from a gaussian core is observed.

Usually we determine the effects of self-absorption by approximating the profile by formula

$$I_\lambda = I_0 \frac{1 - e^{-Nk_\lambda}}{1 - e^{-Nk_0}} \qquad (3)$$

where the absorption coefficient k_λ for the prominence is assumed to be dependent on Doppler effect, i.e., $k_\lambda = k_0 e^{-\left(\frac{\Delta\lambda}{\Delta\lambda_D}\right)^2}$. Curve I_λ, de-

termined by formula (3), has, on graph ($\Delta\lambda^2$, lg I), an asymptote corresponding to a profile with no self-absorption. The inclination of the asymptote is determined by value $\Delta\lambda_\gamma = 1.665\Delta\lambda_D$, and the distance Δ lg I along the ordinate axis between the asymptote and curve lg I_λ, as follows from (3), is equal to $\Delta \lg I = \lg \frac{Nk_0}{1 - e^{-Nk_0}}$. Thus, from a practical point of view, the use of diagrams ($\Delta\lambda^2$, lg I) allows us to estimate conveniently and quickly the effect of self-absorption on a line, and this operation is based on only one investigated profile, without the drawing-up of additional data for $\Delta\lambda_D$, etc.

In the suggested method, we use, on the whole, the rectilinear portion of the profile, in which self-absorption is assumed to be absent, and we do not take into consideration the central portion of the profile, deviating from an approximate straight line. Formula (3) must define this portion of the profile. Usually, (see [6, 7] and others), given different values of $\Delta\lambda_D$ and N, we select a curve, according to formula (3), that best represents the observed points. Self-absorption was determined in this way also, and the results of determination of $\Delta\lambda_D$ and N were compared with corresponding data determined by the first method. The choice of profiles in the second method was determined graphically by the following method. Equation (3) solved for $\Delta\lambda^2$ has the form:

$$\Delta\lambda^2 = -\Delta\lambda_D^2 \ln \frac{\ln\left[1 - \frac{I_\lambda}{I_0}\left(1 - e^{-Nk_0}\right)\right]}{-Nk_0} \equiv \Delta\lambda_D^2 \cdot f(I_\lambda, Nk_0) \quad (4)$$

A curve ($\Delta\lambda^2$, f) was drawn up according to the observed values of $\Delta\lambda$ and I_λ for the central portion of the profile. The points were arranged along a straight line that also passed through the principle coordinate only at determined value lg Nk_0, determined, as is shown by the calculations, with an accuracy up to ± 0.3. Thus, it is necessary to keep in mind that in the case of slight self-absorption effects ($Nk_0 < 1$) there is little accuracy in the determination of N by this method. The inclination in drawing ($\Delta\lambda^2$, f) gives a value $\Delta\lambda_D^2$. The results of the determination of $\Delta\lambda_D$ and N by both methods for the prominences of May 13, 1955 and July 13, 1955 are given in table 2.

TABLE 2

Prominence	Knot	Line	1st Method $\Delta\lambda_D$, Å	$\frac{\Delta\lambda_D}{\lambda} \cdot 10^5$	Nk_0	$N_2 \cdot 10^{12}$	2nd Method $\Delta\lambda_D$, Å	$\frac{\Delta\lambda_D}{\lambda} \cdot 10^5$	Nk_0	$N_2 \cdot 10^{12}$
13 May	2	Hα	0.40	6.1	1.1	2.35	0.41	6.[illegible]	3.9	8.3
		Hβ	0.27	5.6	0.32	5.0	0.35	7.[illegible]	0.96	15
		Hγ	0.21	4.7	0.42	20	0.25	5.[illegible]	1	47
		H	0.19	4.7	1.75	-	0.20	5.0	[illegible]	-
		K	0.20	5.2	1.38		0.20	5.1	[illegible]	-
13 July	1	Hα	0.46	7.0	2.3	4.9	0.35	5.3	6.6	14
		Hβ	0.29	6.2	0.6	9.3	0.21	4.3	4.0	62
		Hγ	0.20	4.7	0.3	14	0.20	4.6	0.9	42
		H	0.26	6.7	0.27	-	0.195	5.0	3.0	-
		K	0.30	7.6	0.74	-	0.21	5.3	3.5	-
	2	Hα	0.37	5.6	3.2	6.8	0.315	4.8	10	21
		Hβ	0.25	5.2	0.75	12	0.18	3.7	4.0	62
		Hγ	0.17	4.0	0.2	9.3	0.15	3.5	1.65	77
		H	0.17	4.2	0.22	-	0.125	3.2	1.5	-
		K	0.16	4.1	0.62	-	0.125	3.2	2.5	-
	3	Hα	0.35	5.3	3.1	6.6	0.315	4.8	5.9	13
		Hβ	0.22	4.6	1.3	20	0.165	3.4	4.0	62
		Hγ	0.19	4.3	0.15	7.0	0.16	3.6	1.25	57
		H	0.14	3.6	0.36	-	0.245	6.2	2.7	-
		K	0.15	3.8	0.78	-	0.25	6.4	3.4	-

From examination of the data in this table one can draw the following conclusions:

1. Neither the first nor the second method of calculation of self-absorption gives identical values of $\frac{\Delta\lambda_D}{\lambda}$ and N_2 for all three hydrogen lines simultaneously.

2. The data obtained by the first method differ from data obtained by the second method. For example, values N_2 differ by 3 to 5 times.

These conclusions point to the incorrectness of the initial premises, i.e., either formula (3) is incorrect for prominences, or coefficients of absorption k_λ cannot be considered as Doppler.

We will consider both assumptions.

1. Correct assumption concerning the Doppler coefficient, but incorrect formula (3). This means that in a non-uniform layer of a prominence the value $p_\lambda = \frac{\lambda}{k}$ changes along the line of sight. Since self-absorption (if it exists) is slight, then in the wings it equals zero. If the coefficient of absorption were Doppler, then, in the results the first method of calculation of self-absorption, using the straight-line portion of the profile, would have to give consistent agreement for all lines. Since this is not so, the first assumption fails.

2. We assume that formula (3) is, nevertheless, correct, but that the coefficient of absorption is not Doppler. For such low densities of material as are observed in prominences, the influence of natural damping or damping due to emission can count as a factor only in the far wings of the profile, where intensity is 0.1% or a smaller fraction of the intensity in the center of the line. It follows, from the calculations of both Verweij [8] and de Jager [9], that combined calculation of Doppler and Stark broadening of a line leads to non-Doppler wings and core of the profile. In this case, consideration of the influence of self-absorption requires additional study. We must observe, however, that it is possible to consider the influence of Stark line-broadening only on the assumption that the density of electrona is $n_e \gg 10^{11}$, which contradicts the present idea of n_e in prominences. Thus, the examination of the behavior of profiles in central portions of H_α, H_β, and H_γ places in doubt both the assumption of the Doppler character of these lines and the assumption of uniformity of a prominence along the line of sight.

As to H and K Ca^+, both methods for investigated prominences reveal very slight self-absorption in these lines. Meanwhile, the values $\frac{\Delta\lambda_D}{\lambda}$ obtained from H and K Ca^+ in the prominence of July 13, 1955 are 1.5 - 2 times greater than the value $\frac{\Delta\lambda_D}{\lambda}$ calculated for lines of Ti^+, in which there is no self-absorption. Since the molecular weights μ of both elements are equal, values $\frac{\Delta\lambda_D}{\lambda}$ for both elements must agree, but since this is not observed, then it is necessary to conclude that formula (3) does not explain the behavior of the line profiles of H and K Ca^+.

In general, the influence of self-absorption is not noticeable in the drawings ($\Delta\lambda^2$, lg I) of the profiles of H_β, H and K for the May 13 (I) prominence; in these drawings the straight-line portions continue to the peak. But the greater val[illegible] of $\frac{\Delta\lambda}{\lambda}$ for these lines in comparison with other lines points to unus[illegible] broadening in them. On the basis of observations of particular profiles of H_α in prominences, characterized by flat or depressed peaks, Ellison [10] reached the conclusion

that there is non-uniformity in the physical conditions of various layers of a prominence. The calculations performed above show that in prominences with usual line profiles, the physical conditions apparently change along the line of sight.

A.B. Severny [11] has shown that the greater the ratio of the observed halfwidth $\Delta\lambda_{obs}$ of the profile to the Doppler $\Delta\lambda_D$, the greater must be the effect of self-absorption. If we use $\Delta\lambda_D$ calculated for Ti^+ lines, then, in the prominence of July 13, 1955 the ratio for H and K of Ca^+ will be $\frac{\Delta\lambda_{obs}}{\Delta\lambda_D} = 1.8 - 2.8$, and for H_α, with the use of $\Delta\lambda_D$ calculated for the higher members of the Balmer series, $\frac{\Delta\lambda_{obs}}{\Delta\lambda_D} = 1.9 - 2.1$. Thus self-absorption in H and K of Ca^+ must be stronger than in H_α, but in Table 2 this is not evident. In addition, the use of A.B. Severny's method, based on the use of ratio $\frac{\Delta\lambda_{obs}}{\Delta\lambda_D}$, results in a value $Nk_0 > 10^2$ for all of these lines, i.e., considerably larger values than those given in Table 2. It is true that the method of A.B. Severny is based also on the use of formula (3) describing self-absorption in uniform layers, but this formula, as follows from the foregoing, is not suitable for prominences.

We turn now to the consideration of the helium lines. As we know, some helium lines are triplets. For example, D_3 consists of 3 components: λ5875.601, λ5875.643 and λ5875.965, having relative intensities of 10, 6 and 2 respectively. Since the halfwidth of D_3 in prominences $\Delta\lambda = 0.4$ Å, the first two components, constituting the core of the line, must be considered as practically coinciding. The third weak component causes the asymmetry of line D_3, as is apparent in Fig. 1. The core of the line, if it is determined only for the blue wing in the upper portion of the profile, is gaussian. Thus the halfwidth of the gaussian core of D_3 was actually determined for one half of the profile, while the equivalent width S was determined for all of the triplets as a whole. Also, we must take into consideration the effect of asymmetry on λ4471, which is a triplet similar to line D_3, since the distance of the third component of this line from the first two is 0.21 Å. From examination of the system of levels of orthohelium, it was determined that in λ3889 the 3rd component is situated to the red side of the line, at a distance of 0.04 Å. Obviously, the influence of this component can be ignored. In the determination of the halfwidths of $H\gamma$ and $He\zeta$ we used those portions of the profile which did not overlap each other.

The results of measurements of halfwidths approximating gaussian profiles $\Delta\lambda_\gamma$ (in Å) are given in Table 3 (column 5). This table also gives measured wave lengths of prominence lines λ (column 4), equivalent widths of profiles S (in Å of continuous spectrum at the center

of the solar disk), and maximum intensities of profiles I_m in units of the continuous spectrum at the center of the solar disk (columns 6 and 7). In column 8 is given the number n of measurements of a given profile on various spectrograms.

No II/II	Line	Knot	λ	$\Delta\lambda_T$, Å	$S \cdot 10^3$	$I_m \cdot 10^3$	n
1	2	3	4	5	6	7	8
			23 March 1955				
1	H_α	1	-	0.455	14.7	25.5	1
2		1	-	0.57	194	285	1
3		2	-	0.465	14.0	21	1
4		2'	-	0.90	28.7	30	1
5		3	-	0.85	38.7	34	1
6		3'	-	0.74	70	65	1
7		4	-	0.49	89	130	1
8	H_β	1	-	0.40	1.55	3.3	1
9		1'	-	0.39	2.37	6.5	1
10		2	-	0.44	2.5	4.7	1
11		2'	-	0.475	2.85	5.2	1
12		3	-	0.415	? 85	6.0	1
13		3'	-	0.54	11.3	18	1
14		4	-	0.35	14.3	41	1
15	H_γ	1	-	0.29	0.62	2.3	1
16		1'	-	0.31	0.80	2.4	1
17		2	-	0.35	0.97	2.3	1
18		2'	-	0 575	7.0	8.4	1
19		3	-	0.325	0.89	2.2	1
20		3'	-	0.67	28	37	1
21		4	-	0.30	7.3	18	1
22	H_δ	1	-	0.34	(0 .4)	(1.0)	1
23		1'	-	0.23:	0.19	1.0	1
24		2	-	0.37	0.71	1.85	1
25		2'	-	0.80	4.1	7.0	1
26		3	-	0.34	0.44	1.2	1
27		3'	-	0.79	9.3	31	1
28		4	-	0.32	2.6	7.2	1
29	D_3	1	-	0.32	0.60	1.6	1
30		1'	-	0.32	1.2	3.0	1
31		2	-	0.42	0.73	1.6	1
32		2'	-	0.39	0.70	1.6	1
33		3	-	0.345	0.60	1.5	1
34		3'	-	0.46	2.0	3.9	1
35		4	-	0.28	2.2	7.5	1

TABLE 3 (Contd)

No II/II	Line	Knot	λ	$\Delta\lambda_{Ts}$ Å	$S \cdot 10^3$	$I_m \cdot 10^3$	n
1	2	3	4	5	6	7	8
			13 March 1955				
36	H_α	1	6562.881	0.702	29.5	26	1
37		2	.858	0.665	44	39.5	1
38	H_β	1	4861.340	0.45	3.9	6.6	1
39		2	.334	0.455	5.2	7.9	1
40	H_γ	1	4340.436	0.38	1.3	2.6	1
41		2	.463	0.345	2.1	3.8	1
42	H_δ	2	4101.730	0.345	0.64	1.4	1
43	H_ϵ	1	3970.099	0.48:	0.62	1.0	1
44		2	.097	0.345	1.45	3.3	2
45	H_ζ	1	3889.045	-	0.35	0.5	1
46		2	.075	0.33	0.28	0.7	1
47	D_3	1	5875.734	0.535	2.0	2.5	1
48		2	.665	0.42	5.8	9.0	1
49	He_ζ	1	3888.616	0.278	0.45	1.45	1
50		2	.636	0.251	0.75	2.05	1
51	H	1	3968.504	0.36	6.6	15.5	1
52		2	.489	0.315	12.1	21.5	2
53	K	1	3933.715	0.39:	8.8	17.0	1
54		2	.663	0.34	13.2	22.6	2
55	H_α	3a	6562.895	2.3	0.98	0.83	1
56	H	3a	3968.531	0.97	0.66	1.3	1
57	K	3a	3933.721	1.0	0.82	1.5	1
58	H_α	3σ	6563.735	1.7	1.27	1.35	1
59	H	3σ	3968.928	0.75	0.98	2.3	1
60	K	3σ	3934.131	0.83	1.43	3.0	1
			13 July 1955				
61	H_α	1	6562.89	0.76	1.75	140	2
62		2	.89	0.61	140	140	2
63		3	.86	0.58	128	137	2
64	H_β	1	4861.42:	0.49	22	37	2
65		2	.347	0.42	19	37	2
66		3	.339	0.37	17	32	2
67	H_γ	1	4340.516	0.34	7.8	20	1
68		2	.486	0.29	6.7	19.5	1
69		3	.480	0.315	4.9	13.5	1
70	H_δ	1	4101.787	0.32	5.1	12	1
71		2	.756	0.285	4.1	13	1
72		3	.761	0.295	3.6	11	1

TABLE 3 (Contd)

No II/II	Line	Knot	λ	$\Delta\lambda_p$, Å	$S \cdot 10^3$	$I_m \cdot 10^3$	n
1	2	3	4	5	6	7	8
			13 July 1955				
73	H_ϵ	1	3970.136	0.32	3.0	8.2	2
74		2	.086	0.27	2.1	7.8	2
75		3	.088	0.28	2.4	6.6	2
76	H_ζ	1	3889.098	0.335	2.7	6.9	1
77		2	.052	0.30	2.3	6.9	1
78		3	.047	0.29	1.7	5.1	1
79	H_9	1	3835.455	0.31	2.1	6.4	1
80		2	.418	0.28	2.0	5.4	1
81		3	.409	0.26	1.4	5.1	1
82	D_3	1	5875.718	0.445	10	16	2
83		2	.709	0.40	8.5	18	2
84		3	.662	0.30	6.0	16	2
85	4471	1	4471.532	0.32	1.3	3.4	1
86		2	.482	0.235	0.85	2.9	1
87		3	.482	0.23	0.96	3.1	1
88	He_ζ	1	3888.702	0.235	1.75	6.0	1
89		2	.674	0.20	1.25	5.2	1
90		3	.645	0.18	0.93	4.9	1
91	H	1	3968.537	0.44	15.5	24	2
92		2	.488	0.28	8.0	24	2
93		3	.475	0.24	6.8	22	2
94	K	1	3933.726	0.50	13.0	23.5	2
95		2	.685	0.27	7.5	23	2
96		3	.667	0.25	6.5	24.5	2
97	Ti^+	1	3761.394	0.17	0.35	0.18	2
98		2	.316	0.17	0.27	0.15	2
99		3	.326	0.155	0.28	0.15	2
100	Ti^+	1	3759.365	0.17	0.37	19.	2
101		2	.290	0.16	0.33	15.5	2
102		3	.305	0.13	0.28	14	2
103	Ti^+	1	3685.275	0.19	0.29	13.5	2
104		2	.205	0.17	0.30	17	2
105		3	.215	0.14	0.20	11	2

TABLE 3 (Contd)

No II/II	Line	Knot	λ	$\Delta\lambda_D$, Å	$S \cdot 10^3$	$I_m \cdot 10^3$	n
1	2	3	4	5	6	7	8
			22 July 1955				
106	H_α	1	6562.853	0.525	81	140	2
107	H_β	1	4861.33:	0.47	5.2	10	2
108	H_γ	1	4340.475	0.435	0.93	2.0	1
109	H_δ	1	4101.814:	0.40	0.36	0.8	1
110	H_ϵ	1	3970.140	0.36	0.23	0.7	2
111	D_3	1	5875.700	0.28	4.1	10	2
112	H	1	3968.505	0.145	5.9	26	2
113		2	.82	0.28	2.3	7.6	1
114		3	.05	0.30	0.32	0.76	1
115	K	1	3933.695	0.14	7.2	28.5	2
116		2	3934.025	0.29	2.35	7.6	1
117		3	3933.255	0.30	0.39	0.95	1

We turn now to the far wings of the profiles. We must point out once again that the determination of the wings is highly uncertain, since their intensities lie, for the most part, within the limits of errors of measurement. Hence the average points, represented in the drawings of Fig. 3 by dots enclosed in circles, give only a general idea of the behavior of the wings. Because of this we observe apparent differences between the blue and red wings, some asymmetry of profiles in the wings, and other phoenomena that, apparently, do not have any real significance. Taking into consideration these observations, one should recognize, nevertheless, that in profiles of spectral lines of prominences the intensity of the far wings is greater than it would be if the profiles had the form of a gaussian curve from the peak to the ends of the wings. Obviously, the profiles of lines of a prominence are more complex. Furthermore, comparisons between profiles of various lines show that the deviation of the wings from a gaussian curve, measured in the upper portion of the profile, is less for hydrogen lines, greater forlines H and K Ca^+ and most strongly pronounced of all in helium lines. In this respect the comparison of H_γ and He_γ in Fig. 3 gives a clear example. For the 3 investigated lines of Ti: λ3685, λ3759 and λ3761, it is possible that, because of insufficient accuracy, we do not see definitely pronounced wings diverging from a gaussian curve determined by the core of the line.

For the purpose of the following discussion, 2 methods of describing the wings were used. Examination of drawings ($\Delta\lambda^2$, lg I) pertaining to lines

He and Ca+ affords a basis for assuming that points in the wings of the profiles also lie along some straight line, i. e., that they also can be approximated by some gaussian curve, but with halfwidths greater than the halfwidth of the central portion of the line. In this case the profile is represented in the form of a superposition of two gaussian curves; - narrow and bright for the core, and broad but weak for the wings. The presence, in observed profiles, of Doppler wings with great halfwidths may have been confirmed by V.A. Krat's [12] hypothesis of the co-existence of hot and cold gases in the chromosphere.

On the other hand, an attempt was made to represent the wings of the profile by a formula in the form $I \sim \Delta\lambda^{-a}$, where $\Delta\lambda$ is the distance from the center of the profile. The most reliable measurements of wings were done for the prominence of July 13, 1955. However, greater errors were found in these measurements. The results of the determination of values a, and also the reduced halfwidths of second gaussian curves $\frac{(\Delta\lambda_{\Pi})^2}{\lambda}$ for each wave length, averaged for all measurements of the prominence, are presented in Table 4.

TABLE 4

	H_α	H_β	H_γ	H_δ	H_ϵ	H_ζ	H_η	D_3	He ξ	H	K
$\frac{(\Delta\lambda_{\Pi})^2}{\lambda} \cdot 10^5$	15.3	13.1	9.5	8.5	11.3	8.9	14.3	15.6	10.9	15.3	17.3
a	8.4	8.0	8.1	5.6	4.9	8.15	6.15	6.9	7.6	5.1	4.9
$(\lg I)_{wing}$	2.0	11.3	0.8	0.9	11.0	1.2	0.85	1.2	0.7	0.85	1.1
$(\Delta\lambda)_{wing}$	0.72	0.48	0.32	0.28	0.26	0.24	0.235				

Also in Table 4 are shown values $(\lg I)_{wing}$ and $(\Delta\lambda)_{wing}$ where the deviation of the wing from a gaussian curve for the core begins. In Fig. 3, as an example, in H_β the wing begins approximately with the point on the profile defined by coordinates $(\lg I)_{wing} = 1.4$ and $(\Delta\lambda)_{wing} = 0.22$.

5. ACCURACY OF THE MEASUREMENTS

Before turning to a discussion of the material it is necessary to consider the question of the accuracy of the determination of various parameters of the profile.

In the method used for photography of the spectra, the absolute values S and I_m, and their relationship to intensity at the center of the solar disk do not permit us to obtain accuracy above 20%, as is shown in comparing results of various measurements. Relative changes in values S and I_m, comparing various portions of one prominence, are more reliable.

As has already been noted, in the majority of cases wave lengths of various lines are measured with an accuracy of $\pm$ 0.01 A.

The determination of parameters a and $(\Delta\lambda_{\Gamma})_2$ for wings of the profile is highly unreliable, as is shown by comparison of results of various measurements of profiles of one line pertaining to a single place in the prominence. These parameters, - and also values $(\lg I)_{wing}$ and $(\Delta\lambda)_{wing}$, indicating the place on the profile at which the far wings begin, - give only a general idea of the wings of the profile.

The basic consideration in the present work was given to obtaining possibly more precise values of halfwidths of profiles. Naturally, the determination of one halfwidth or even 3 widths (see [1]) on the drawings where smoothed contours are drawn in is insufficently accurate. Besides, experience shows that the greater uncertainty in the determination of $\Delta\lambda$ thus introduces inaccuracies in the measurement of I_m of the profile. In the present work, all measured points of the profile were used, for which we selected gaussian curves that most satisfactorily represented these points. It is of interest to estimate the accuracy of the method used. With this goal in mind, the coefficients of linear dependence associated with the observed values $\Delta\lambda^2$ and lg I were calculated for several profiles of $H\gamma$ and $H\delta$ by the method of least squares. In the calculations neither the points defining the far wings of the profiles nor the points defining the peaks of profiles for line $H\gamma$ were taken into consideration, since they were distorted by self-absorption. The average quadratic error of the calculated coefficients of linear dependence, which were proportional to $\Delta\lambda^2_{\Gamma}$, was $\pm$ 2 - 5%. The average error of determination of $\Delta\lambda_{\Gamma}$, was, naturally, two times less.

For greater exactness, computations with calculations of weight of the measurement of each point on the profile were performed. Since errors in measurement of intensity ΔI were practically constant for all of the profile, the weight was taken as equal to the ratio $\frac{1}{\Delta I}$. These calculations gave the same values of average quadratic error. The results of the graphical determination of $\Delta\lambda_{\Gamma}$ and both series of calculations agree well with each other within the limits of calculated error. Hence, the graphical method of determination of $\Delta\lambda_{\Gamma}$, which has advantages of simplicity and clearness, was used. For the weaker lines it is natural to expect an increase of error in determination of $\Delta\lambda_{\Gamma}$, since the value of relative error in intensity of profile $\frac{\Delta I}{I_m}$ increases. Thus, it is necessary to keep in mind that this error has a tendency to lead to an under-estimated determination of $\Delta\lambda_{\Gamma}$. In fact, with a constant error in ΔI, points lg $(I - \Delta I)$ systematically deviate more sharply from a straight line than points lg $(I + \Delta I)$, since the value $I - \Delta I$ differs more in percentage ratio from I than does $I + \Delta I$.

Special drawings were constructed which showed that for errors $\frac{\Delta I}{I_m}$ a: 10% there is possibly a 5% under-estimation of the values $\Delta\lambda_{\Gamma}$ determined according to the drawing.

The determination of zero intensity of the profile depends considerably on the accuracy of determination of $\Delta\lambda_{\Gamma}$. Hence, for measurements of profiles care was taken in determining the zero intensity of the profile that no less than 10 - 20 points on the spectra of the halo were obtained on each side of the measured line. Special attention was given, also, to the elimination of the influence of scattered light inside the spectrograph. On some plates, in the yellow-red portion of the spectrum this scattered light gave spurious images, the intensity of which attained 20% of the value of the intensity of the spectrum in the halo.

6. DISCUSSION OF THE RESULTS OBTAINED

We will draw briefly some basic conclusions, following from the examination of the results of profile measurements. First we consider the halfwidths of lines In Table 5 are given values of reduced halfwidths, i. e., values $\frac{\Delta\lambda_{\Gamma}}{\lambda}$, which, for convenience, are multiplied by a factor of 10^5. One should keep in mind that the measurements for the prominence of March 23, 1955 are less precise than those for other prominences.

We turn now to the data for hydrogen lines. As follows from formula (2), $\frac{\Delta\lambda_{\Gamma}}{\lambda}$ must be the same for all lines of one chemical element. Meanwhile, from Table 5, it follows, first of all, that although $\frac{\Delta\lambda_{\Gamma}}{\lambda}$ are nearly constant for the higher members of the Balmer series, they are often appreciably greater for lines H_α and H_β, although the influence of the effect of self-absorption on $\frac{\Delta\lambda_{\Gamma}}{\lambda}$ is eliminated by the method used for obtaining these values. In the consideration of the question of self-absorption, the conclusion was drawn above that the broadening of these lines was caused, apparently, not by Doppler effect alone. Comparison of $\frac{\Delta\lambda_{\Gamma}}{\lambda}$ for H_α and H_β with the reduced halfwidths of other hydrogen lines confirms this conclusion.

In article [1] the conclusion was drawn that $\frac{\Delta\lambda}{\lambda}$ increases with the number of the line in the Balmer series, and that the gradient of this increase $\frac{\delta\Delta\lambda/\lambda}{\delta n} = 1.3 \cdot 10^{-5}$, on the average, for all of the observed material. If we exclude H_α and H_β from consideration, the greater values of which represents a special question, then the increase of $\frac{\Delta\lambda}{\lambda}$ with the number of the line, apparently, is confirmed for the rest of lines in Table 5. However, the value $\frac{\delta\Delta\lambda/\lambda}{\delta n}$, calculated according to the most reliable data for the prominences of May 13 and July 13, is only $0.2 \cdot 10^{-5}$, and is close to the value for the mean square error (for the prominence of July 13 (3) even a negative value was obtained).

TABLE 5

Prominence	Knot	H_α	H_β	H_γ	H_δ	H_ϵ	H_ζ	H_η	$\bar{H}$	$\frac{\delta\Delta\lambda/\lambda}{\delta n}$	D3	λ 4471	He	Ti^+	H	K
23.III	1	6.95	8.2	6.65	8.3	-	-	-	7.52	-	5.4	-	-	-	-	-
	1'	8.7	8.0	7.2	-	-	-	-	8.0	-	5.4	-	-	-	-	-
	2	7.1	9.0	8.05	9.0	-	-	-	8.29	-	7.1	-	-	-	-	-
	2'	13.7	9.75	13.2	19.5	-	-	-	-	-	6.65	-	-	-	-	-
	3	12.9	8.5	7.5	8.3	-	-	-	8.1	-	5.9	-	-	-	-	-
	3'	11.3	11.1	15.4	19.3	-	-	-	-	-	7.8	-	-	-	-	-
	4	7.5	7.2	6.95	7.8	-	-	-	7.36	-	4.8	-	-	-	-	-
13.V	1	10.7	9.2	8.8	-	-	-	-	8.8	<0	9.1	-	7.15	-	9.1	9.9
	2	10.1	9.3	7.9	8.4	3.7	8.5	-	8.38	0.21±0.12	7.2	-	6.45	-	7.9	8.65
	3a	10.4	-	-	-	-	-	-	-	-	-	-	-	-	7.6	8.4
	3b	14.0	-	-	-	-	-	-	-	-	-	-	-	-	9.8	10.2
13.VII	1	11.6	10.1	7.8	7.8	8.05	8.6	8.1	8.05	0.14±0.09	7.6	7.15	6.05	4.8	11.1	12.7
	2	9.3	8.6	6.7	6.95	7.0	7.7	7.3	7.13	0.20±0.10	6.8	5.25	5.15	4.45	7.05	6.85
	3	8.8	7.6	7.25	7.2	7.05	7.45	6.8	7.15	-0.06±0.07	5.1	5.15	4.6	3.8	6.05	6.35
22.VII	1	8.0	9.65	10.0	9.75	9.05	-	-	9.3	-	4.75	-	-	-	3.6	3.55
	2	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0	7.4
	3	-	-	-	-	-	-	-	-	-	-	-	-	-	7.5	7.6

However, one should remember that $\Delta\lambda_{\Gamma}$, because of errors of determination of intensities of points on the profile, may be somewhat underestimated. Hence, since the relative error of $\frac{\Delta I}{I_m}$ increases for high members of the Balmer series which have lower intensities, then to the same extent the danger increases of under-estimating $\Delta\lambda_{\Gamma}$, and consequently $\frac{\delta\Delta\lambda/\lambda}{\delta m}$. For the developing coronal prominence of July 22 (1) the calculation of $\frac{\delta\Delta\lambda/\lambda}{\delta m}$ was speculative, since various lines were photographed at various stages of development of the prominence; and from the data of Table 5 it follows, apparently, that $\frac{\Delta\lambda}{\lambda}$ increased during the development of the prominence, and, having reached a maximum, then decreased. This conclusion finds further confirmation in the fact that, for D_3, $\frac{\Delta\lambda}{\lambda}$ proves to be as much as 2 times smaller than $\frac{\Delta\lambda}{\lambda}$ for lines H_β, H_γ and H_δ (photographed later than line D_3), which is absurd from the standpoint of the use of formula (2) with helium and hydrogen lines observed simultaneously, and shows that H_β, H_γ and H_δ are additionally broadened. This conclusion concerning the change in $\frac{\Delta\lambda}{\lambda}$ in the process of development of a prominence is interesting in itself. For the prominence of March 23 an insufficient number of lines was observed and the accuracy of the measurements was less, since all the precautionary measures described in §1 were not strictly observed. Nevertheless, a comparison of lines H? and H_δ shows that the latter line is systematically broader than the first. Thus, the investigated material apparently confirms the fact of the increase in $\frac{\Delta\lambda}{\lambda}$ with the number of the line.

We now consider the results of measurement of halfwidths of helium lines. The comparison of $\frac{\Delta\lambda}{\lambda}$ for D_3 and Heγ shows that the reduced halfwidths for the first line are systematically greater than for the second. The fact was noted for the first time in the dissertation of M. V. Bratiichuk [13]. Although the data for He λ4471 are less reliable, they show that this line occupies an intermediate position between D_3 and Heγ. Thus D_3 and λ4471 have some kind of additional source of broadening in comparison to Heγ. Apparently, this is partially connected with the fact that the cores of lines D_3 and λ 4471 are close doublets. Calculations show that, by superposition of two gaussian profiles that are slightly displaced from each other, the halfwidth of the whole profile, - determined graphically by means of the function $(\Delta\lambda^2, \lg I)$, - increases by a value somewhat smaller than the distance between the displaced profiles. Thus the doublet character of the core results in an increase of the width of the line; however, this increase is sometimes less by a factor of two than that observed.

We now examine the comparisons of halfwidths of lines of various elements. If formula (2) is true for prominences, then there must be a linear relationship between values $_T$ and $\left(\frac{\Delta\lambda}{\lambda}\right)^2$. In Fig. 4 we compare data for lines of hydrogen, helium and titanium for the prominence of July 13, 1955. The value of $\frac{\Delta\lambda}{\lambda}$ for hydrogen was obtained by averaging $\frac{\Delta\lambda_\Gamma}{\lambda}$ for the higher members of the Balmer series, beginning with Hγ. This

value is given in Table 5, column $\bar{H}$. For helium $\frac{\Delta\lambda_T}{\lambda}$, determined for He λ3889, was used. For all three parts of the prominence of July 13 the data for hydrogen, helium and titanium lines really follow a straight line, within the limits of accuracy of the measurements. This fact shows that the profiles of weak metallic and hydrogen lines, and also He λ3889 have, on the whole, Doppler broadening.

The inclination of the straight line in Fig. 4 gives T_{kin}, and its intersection with the ordinate axis gives v_t^2. The values T_{kin} and v_t for each part of the prominence, calculated by the method of least squares, are given in Table 6.

TABLE 6

	Prominence 13 May 1955		Prominence 13 July 1955		
	Knot		Knot		
	1	2	1	2	3
T_{kin}	6950°	7550°	8150°	6300°	7500°
v_t, KM/cek	11.7	10.2	8.8	7.8	6.4

In the calculation of Tkin and v_t for the prominence of May 13, half-widths of the hydrogen lines and He λ3889, only, were used.

We turn now to the data for the wings of the profiles, presented in Table 4. The data in this table shows that : 1) the deviation of the wings from a gaussian curve, determined for the upper portion of the profile, increases roughly with intensity, being 10% of maximum intensity I_{max}; 2) the sharpest (large α) decrease of intensity of the wings occurs in hydrogen, especially for the first lines of the Balmer series, and the smallest decrease occurs in the lines of Ca^+ ; 3) the idea of wings as gaussian curves leads to the conclusion that half-widths approximating gaussian curves increase as the lines are brighter (greatest for line Ca^+), and the dependence, according to formula (2), on the value of the molecular weight μ does not appear to be typical for Doppler profiles, as it is in the cores of lines. Thus, the idea that the wings of the profiles can be caused by hot components of gases in a prominences fails. On the other hand, too great a value of α prevents us from concluding that we are dealing with Stark wings, for which α = 2.5, or with wings of radiation damping, for which α = 2.0. Apparently in profiles a transitional region between the Doppler core and the far wings is measured, on the nature of which various assumptions can be made. The presence of slowly decreasing wings in the profiles of lines Ca^+ presents a special difficulty.

In connection with this the following fact is pertinent. On photographs of spectra of H and K obtained with over-exposures, it is frequently apparent that, beneath dark lines of emission with a well-marked core, some kind of broad, diffuse, and often amorphous image shows through. In some cases it is evident that this spurious image consists of separate (detached) knots, having various Doppler displacements. In all probability, in the results of measurements of wings, where we deal with such small values of intensity, the eye can no longer distinguish them on the plate, and rejects the presence of such spurious images.

TABLE 7

Prominence	Knot	Wave Length, Å							Mean $\frac{\delta\lambda}{\lambda}\cdot 10^6$
		6562.79	4861.327	4340.465	4101.735	3970.074	3889.055	3835.397	
13.V.	1	14	3	-7	-	6	-3	-	5
	2	11	1.5	-1	-1	6	-4	-	2
	3a	16							15
	3б	144							126
13.VII	1	18	21:	12	13	16	11	15	16
	2	15	4	4.5	5	3	-1	5.5	4
	3	11	2.5	3	6	3.5	2	3	3
22.VII	1	10	1	2	19	17	-	-	10
Chromosphere		2	34	31	28	43	32:	37	23

TABLE 7 (Contd)

Prominence	Knot	Wave Length, Å								Mean $\frac{\delta\lambda}{\lambda}\cdot 10^6$
		5875.62	4471.48	3888.65	3968.468	3933.666	3761.323	3759.295	3685.195	
13.V	1	19	-	-9	9	12	-	-	-	5
	2	8.5	-	-5	5.5	-1.5	-	-	-	2
	3a				16	14	-	-	-	15
	3б				116	118	-	-	-	126
13.VII	1	17	11	13	17	15	19	19	22	16
	2	15	0	6	5	5	-2	-1	3	4
	3	7	0	1	2	0	1	3	5	3
22.VII	1	14	-	-	9	7	-	-	-	10
Chromosphere		3	13		58	59		9	15	28

One must take this circumstance into account in subsequent study of the far wings of the profiles.

In conclusion we consider the question of wave lengths of spectral line for the investigated prominences. Spectral lines of a prominence can be displaced, firstly, due to their motion relative to the observer (Doppler shift), and secondly, due to the influence of the physical conditions of the atomic matter in the prominence. It is of interest to ascertain whether the physical conditions in prominences influence the positions of spectral lines. For this purpose, it is necessary to isolate Doppler shift. This can be done on the basis that it obeys the equation

$$\frac{\delta\lambda}{\lambda} = \frac{v}{c} = \text{const}$$

independently of wave length and kind of atom of the emitting spectral line. In Table 3 are given results of measurements of positions of lines in the spectra of the prominence relative to lines of the spectra of the sun, which introduce some Doppler shift in the wave lengths of the prominence due to the motion of the sun with respect to the observer. We determine the line shift $\delta\lambda$, after having taken the difference between the measured wave lengths of prominence lines and wave lengths of corresponding lines in the table of spectral lines [14], which we assume (within the limits of accuracy of measurements) to be free of displacement caused by either motion or the influence of physical conditions. In Table 7 are given values of $\frac{\delta\lambda}{\lambda} \cdot 10^6$ for all measured lines.

Wave lengths of lines are given according to [14]. In the last column of Table 7 are given the average values $\frac{\delta\lambda}{\lambda}$. We must remember that the average error of measurement of values $\frac{\delta\lambda}{\lambda}$ is equal to $\pm$ 2:10^{-6} in the majority of cases, but it can be greater for weak lines. Analysis of the data in Table 7 shows that the majority of lines in prominences have displacements which, within the limits of accuracy of the measurements, should be considered as Doppler. In the table, the bold type designates values that sharply differ from $\frac{\delta\lambda}{\lambda}$ and indicates non-Doppler shift of lines; let us consider them. First of all, apropos of the results of measurements of wave lengths of lines of the prominence of July 22 one should observe, once again, that various lines of the prominence were photographed at different stages of its development, and, hence, cannot be compared with each other. From among the rest of the data provided in the table we turn our attention to the values for lines H_α and D_3, which, in some of the cases investigated, reveal a non-Doppler shift, the value of which is several times larger than errors in measurement. In connection with this revealed effect of the behavior of lines H_α and D_3 in prominences, we note that, according to Mitchell's material [15] (see bottom line in Table 7), the abnormal behavior of these lines also occurs in the chromosphere. The cause of the displacement of D_3 may be molecular Stark effect; the displacement of H_α is more difficult to explain. It should be emphasised that inferences about the non-Doppler displacement of H_α and D_3 are not connected with the method of obtaining the values of displacement $\delta\lambda$, since simple differential measure-

ments of line displacements for the three knots of the prominence of July 13, photographed on one spectrogram, reveal abnormal behavior of these lines. A similar inference was drawn, concerning line H_α, for the prominence of May 13 (3).

In the prominence of May 13, side by side with the main knots (1) and (2), an intense, faintly luminescent knot was observed, moving with great velocity. Profiles of lines H_α, H and K were measured for this knot. They differed sharply in form from a gaussian curve. In order to carry out an analysis of these profiles, we drew them up one under another, taking a value $\frac{\Delta\lambda}{\lambda}$ as the abscissa axis (Fig. 5). The profile of H_α is somewhat more complex than the profiles of H and K, which can easily be separated into 2 gaussian profiles, displaced from each other (shown by dashed lines in Fig. 5). For the construction of the left-hand wing of the right-hand component a, we drew a mirror image of the right wing (symmetrically, relative to the peak), and we obtained the left-hand component b as the difference between the common profile and the right-hand component. Following the example of H and K, the profile of H_α was also separated into two parts. Although the procedure of separation of one complex profile into several components is not simple, in the given case the constructed separation, apparently, cannot cause serious objections. The data for each constructed profile are given in Table 2.

Apropos of the contours obtained for the two components, two observations should be made.

1. Wave lengths of the components b for all three lines conform to Doppler shift, but the displacement of component a in line H_α is considerably greater than in lines of Ca^+. Thus, here also the differential measurements display abnormal behavior of line H_α.

2. If we consider that the profiles of the components do not contain self-absorption, then, on the basis of formula (2), we obtain a temperature $T = 11,200°$ and turbulent velocity $v_t = 14$ km/sec for knot a and $T = 24,500°$ and $v_t = 17.5$ km/sec. for knot b.

The present work sets forth only the first investigations of prominences obtained with the new BST instrument. The investigations conducted show the magnificent quality of the BST spectrograph, manufactured by the Soviet industry.

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CAPTIONS

Fig. 1. Profiles of emission lines in the prominence of July 13, 1955 (2). Along the abacissa axis - Angstroms, along the ordinate axis - scale of intensities in units of 10^{-3} of intensity of the continuous spectra at the center of the solar disk. Averaged curves are drawn in the wings of the profiles.

Fig. 2. Profile of $H\gamma$ of the prominence of July 13, 1955 (3) with displacement of axis $\Delta\lambda$ 0.005 A from the center of the profile, in the blue (above) and red (below) portions of the spectrum
X's pertain to the blue wing of the profile, and dots pertain to the red. Along the abscissa are placed the squares of the distance from the center of the profile in Angstroms - along the ordinate axis, logarithms of intensity.

Fig. 3. Profiles of lines of July 13, 1955 prominence (2).
Designation same as in Fig 2. Circles enclosing points pertain to averaged wings.

Fig. 4. Comparison of reduced halfwidths of various elements for various parts of the prominence of July 13, 1955.
Black circles, - part 1, white circles - part 2, X's - part 3.

Fig. 5. Profiles of lines of the May 13, 1955 prominence (3).
Along the abscissa axis are placed values $\frac{\lambda}{\lambda} \cdot 10^5$, along the ordinate axis - scale of intensities in units of 10^{-3} of intensity of continuous spectrum at the center of the solar disk. Dashes show the separation of profiles into two components.

BIBLIOCRAPHY

1. G. S. Ivanov-Kholodnyi. Izv. Crim. Ast. Obs., 13, 112, 1955; 15, 69, 1955
2. A. B. Severnyi. Izv. Crim. Ast. Obs., 15, 31, 1955
3. R. Wilson. Observatory, 73, No. 876, 170, 1953
4. R. Wilson. M. N., 113, 557, 1953
5. V. A. Krat. Bul. Solar Data 1956, No. 1 page 106, 1956
6. M. Conway. Proc. Roy. Irish. Acad., 54, 311, 1952
7. B. L. Khokholova and I. I. Nazaroba. Izv. Crim. Ast. Obs., 11, 170, 1954
8. S. Verweij. Publ. Astr. Inst. Amsterdam, No. 5, 1936
9. C. de Jager. Rech. Utrecht, 13, part 1, 1952
10. M. Ellison. Estratto dagli atti dell' XI Convegno Volta, Roma, 1952
11. A. B. Severnyi. Izv. Crim. Ast. Obs., 12, 33, 1954
12. V. A. Krat. Dokl. Akad. Nauk. USSR, 166, 619, 1956
13. M. V. Bratiichuk. Candidate's Dissertation, Kiev, 1956
14. A. N. Zaidel', V. K. Prokof'ev, S. M. Raiskii. Tables of spectral lines. Govt. Techn. Pub. House, 1952
15. S. Mitchell. Ap. J., 105, 1, 1947